by Henry W. Boger

SMART VALVES

Flow Conditioning Technology

The commercial world looks toward continuous improvement in productivity and product quality. Efforts toward achieving these improvements are often initiated by upper management and span an entire enterprise.

In the process industries, engineers are searching for more efficient ways not only to increase throughput, but at the same time, to improve product quality. To use current phraseology, one tactic is to reduce product variability.

Development and refinement of process control instrumentation has led to improved measurement of process variables, and improved control through the benefits of distributed control systems. These improvements have highlighted the limitations of the performance of final control elements. The final control element is most frequently a control valve. In this context, the control valve is the entire control valve system, that is, the valve body assembly, actuator, positioner, and other accessories. Because control valves have been identified as often being the limiting element in improving performance of the control loop, emphasis is being placed on developing knowledge of important performance characteristics of control valves. Developing such knowledge requires implementation of standard test procedures and measurement tools. One important effort relative to this is the work of an ISA committee in developing standard test procedures detailing control valve response to step inputs. The committee has progressed well towards the goal of creating a standard and a supporting technical report.

It is inevitable that control valves will be scrutinized in more detail in the future. It is to be expected that improved performance will be defined, achieved, and provided on a regular basis.

THE SMART POSITIONER

One of the newer devices that offer improved performance of control valves is the smart positioner. A smart positioner is a microprocessor-based electronic positioner that derives benefit from digital programming to obtain improved positioning performance. Some models offer predictive maintenance and diagnostic benefits as well.

An advantage of the smart positioner is that it may be programmed to use a position control algorithm to achieve better dynamic response than standard pneumatic positioners. Position control settings for a particular valve and actuator are initially established using automatic tuning. After the smart positioner is mounted, a calibration and auto-tune program establishes the normal settings to produce the desired response for the specific valve/actuator assembly. Adjustments can also be made to alter dynamic response. This may include the introduction of moderate overshoot to obtain position quickly with desired damping. Alternatively, if no overshoot is desired, a crisp response with no overshoot is achievable. Using these types of capabilities, the smart positioner can be customized to provide maximum operating efficiency for any specific valve and actuator configuration.

In a recent refinery application, the flow rate controlled by a large valve appeared on the DCS recording to limit cycling by approximately 8% of full scale. The existing electro-pneumatic positioner was replaced by a smart positioner, which was calibrated and auto-tuned accordingly. Without any other adjustments to the DCS, the improved valve performance was immediately evident on the DCS recording. After tuning the DCS, the recording showed essentially flawless performance.

If changes are desired after installing and auto-tuning a smart positioner, then new position control settings may be entered locally at the positioner, or remotely using frequency shift keying for communication. This may be done using a hand-held communicator or via a PC using proprietary software. Today, this type of communication is typically achieved by processing signals over existing analog wires. Additional benefits and capabilities will be possible by using 2-way digital communication provided by fieldbus technology.

Going a step beyond the smart positioner capabilities already described, there is the opportunity to program PID control functionality right into the microprocessor of the positioner. If process transmitter outputs are routed through a smart positioner with PID control capability, then a local control loop can be essentially created (provided the control valve is equipped to manipulate the measured variable). The ability to perform final control functions in the field removes a control loop from the DCS, and offers tighter process control resulting in improved productivity and quality of the final product.

THE SMART VALVE

Whereas a smart positioner is a separate component of a traditional control valve assembly, a smart valve is a complete stand-alone system that includes the valve, actuator, sensors, positioner, and controller. A smart valve, as defined for this article, is a valve with a smart positioner having control capability, integrated seamlessly with various process pressure and temperature sensors installed within the valve body. The purpose of the sensors is to monitor the process upstream pressure, downstream pressure, and temperature through the smart positioner/controller. Flow rate through the valve can be calculated by using the pressure and temperature measurements in conjunction with measurements for valve travel. Thus the smart valve can double as a flow meter as well. The positioner/controller must initially have information on the process fluid state (liquid or gas/vapor), mass density, and other significant data. It must also contain information on the inherent flow characteristic, i.e. the valve flow capacity versus valve travel for the specific valve configuration. The smart valve may be configured to control pressure, temperature, or flow rate at the valve.

In addition to doubling as a flow meter, pressure transmitter, and/or temperature transmitter, smart valves can also provide significant advantages via the predictive maintenance and diagnostic features offered by the smart positioner. Integral pressure sensors at the upstream and downstream flanges sense pressure differential, while another sensor determines valve position, allowing the calculation of flow rate. The multivariable sensing capabilities of a smart valve reduces the cost of installation significantly compared with installing individual conventional control valves, flow meters, controllers, and associated instrumentation. The number of pipe penetrations within the process loop is reduced as well.

Smart valves can provide significant benefits; however, a major limiting factor is the accuracy of the upstream and downstream pressure measurements achievable within the valve body. Sensors are typically mounted at locations near the inlet and outlet flanges, or at other valve body locations that could yield acceptable measurements. It is well known that specific instructions must be observed for the proper installation of flow meters in order to obtain acceptable measurement accuracy. Questions arise as to the influence and cause of the uncertainty of pressure measurements under this scenario.

An independent flow laboratory test program was devised to obtain a reliable determination of the uncertainty of the calculated flow rate as compared to measured flowrate. In a series of laboratory tests, the uncertainty of pressure measurement led to deviation of calculated flow rate from measured flow rate of up to 2%. The flow rate was measured by a calibrated turbine flowmeter. Calibration of a flowmeter is normally done at a certified calibration laboratory using a weight-time method, where weight is traceable to the National Bureau of Standards and time is traceable to the Naval Observatory or an atomic clock. The results determined in this testing program might suffice for some purposes, but is not considered to be broadly applicable or useful for the process control industry.

In a more pertinent laboratory study conducted some time ago, a three-dimensional plastic model of half a valve body was constructed with a thick clear plastic window. The model was mounted in a water flow piping system in the flow laboratory. Flow visualization techniques were used to observe flow, and high-speed video equipment recorded the events. The film was then projected at normal speed to show the flow with visualization techniques in slow motion. The flow downstream of the valve trim was extremely chaotic. A rendition of flow by an artist that shows smooth path lines is completely misleading (except for cold molasses at low-pressure drops). The description of the downstream flow as extremely chaotic is quite accurate. With this picture in mind, it is not surprising at all that pressure measurement in the valve body results in considerable uncertainty and with random fluctuation.

A CONCEPT FOR IMPROVEMENT

Statements on accuracy and uncertainty for flowmeters assume steady flow of a Newtonian fluid with an approach velocity profile, which models the profile that is obtained in long straight pipes. This is the reason that flowmeter installation practices dictate extraordinarily long pipe runs. A desirable velocity profile is fundamental for accurate flowrate determination by a device that produces a pressure differential.

Distortion of the velocity profile can result from one of the following or a combination of the following items; (1) swirl that causes rotation about the axis of the pipe; (2) secondary flows, such as two or more counter-rotational vortices perpendicular to the pipe axis; (3) an asymmetrical profile that peaks near the wall; or (4) a symmetrical profile that has a high-core velocity. In combination, these factors can result in radial, tangential, and axial velocity vectors that are not symmetrical (Miller 1983).

When flowmeter installations are planned for process plant use, it is not possible in some installations to provide sufficient lengths of straight pipe to produce an acceptable reference velocity profile. Flow conditioners are used in combination with reduced pipe lengths for this reason.

Tube bundle flow conditioners are commonly used with flowmeters to remove swirl of the fluid and to provide a desirable velocity profile. AGA-ASME tube bundle conditioners are widely used upstream of orifice flow meters. However, the tube bundles also have specified lengths of two to ten pipe diameters, thus necessitating long laying pipe lengths in a straight run.

A more compact flow conditioner (Akashi et al 1979, Miller 1983) which has better performance and greatly reduced length, consists of precisely arranged circular flow passages in a plate. This results in the possibility of a much more compact installation. The concept of this design principle has been used within a new device.

In order to obtain an accurate measure of static pressure in a flowing fluid, it is important that the measuring device fit the streamlines so that no disturbance is created in the flow. Furthermore, when measuring the static pressure in a flow passage, it is desirable to have multiple openings around the periphery of the section leading into a common channel where pressure is averaged (Daugherty 1977). This design principle is incorporated into the new device as well.

The primary objective in the development of this novel approach was to, achieve the beneficial performance of a superior flow conditioner in a short axial length. A secondary objective was to obtain the benefits of averaging pressures measured at several different locations.

Multiple-hole flow conditioners have been shown in laboratory testing to be superior to tube bundle flow conditioners in terms of removing swirl and in producing a velocity profile closer to the desired reference velocity profile. The principle of pressure averaging has been employed in flow devices such as the classic venturi tube. Typically, four equally spaced holes are designed to lead directly into an annular pressure-averaging channel.

Using these principles, a novel design was created that incorporates flow conditioning and pressure averaging in a single device. This improved device is illustrated in *Figure 1*. Upstream and downstream inserts are used with the flow-conditioning portion upstream of the pressure-averaging channel in both cases. This improved pressure measurement system is the subject of United States Patent Number 5,728,942 and additional foreign patents or applications. The purpose of this device is to reduce the uncertainty of upstream and downstream pressure measurements, allowing for improved accuracy of flow rate determination.

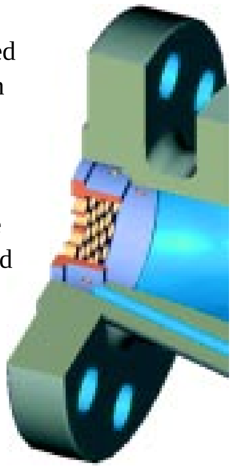

Figure 1

LABORATORY TESTING

In order to determine the benefit and effectiveness of these devices in a quantitative evaluation, a series of flow laboratory tests were devised using a globe valve with pneumatic actuator and positioner. The valve body was modified to allow the installation of upstream and downstream flow conditioners, and to provide the pressure averaging channels.

The valve was tested in the Masoneilan flow laboratory located in Avon, MA. This flow laboratory is equipped to test control valves in accordance with current ISA and IEC testing standards. The inherent flow characteristic (valve flow capacity versus valve travel) was determined using a computer-based data acquisition system. System piping met the requirements of current standards, but with pressure measurement made in the valve body equipped with the flow conditioners.

Test runs were then conducted at several travel positions, and test runs were conducted at a range of several pressure drops for each of the travel positions. Flow at each pressure drop and each travel position was calculated using the pressure drop measured with the flow conditioning and pressure averaging devices installed in the valve. The flow equation used was the liquid flow equation in ISA Standard 75.01. Flow was measured by a calibrated turbine flowmeter permanently installed in the laboratory. Calculated flow was then compared to measured flow.

The percent deviation of calculated flow from measured flow was determined for different pressure drops and different travel positions. The deviations fell within 0.25%. Earlier testing of a globe valve without flow conditioners produced a deviation of 2%. Before the test runs were conducted, it was expected that the flow conditioners would provide an improvement in the range of 2-to-1 or 4-to-1; however, a reduction in the deviation in flow by a factor of eight was unexpected. This improvement is due to flow conditioning and pressure averaging at the inlet and outlet flanges, together with rapid averaging and updating of multiple data points by the data acquisition system.

All of the test runs conducted in this evaluation used water as the test fluid. The pressure drop and resulting flow rates assured fully turbulent flow with high Reynolds numbers. Line pressures were high enough in relation to pressure drop and in relation to the pressure recovery characteristics of the globe valve to assure non-vaporizing flow.

In summary, the combined benefits of flow conditioning and pressure averaging in this patented device have made a significant improvement in the accuracy of flow determination in a typical control valve.

Mr. Boger is an Engineering Consultant with Dresser Valve
Division, Masoneilan Operations
Avon, Massachusetts www.masoneilan.com.

REFERENCES

- *Akashi, K., H. Watanabe, and K. Kenichi: "Development of New Flow Rectifier for Shortening Straight Pipe Length of Flowmeter", Tokyo Flow Symposium, IMEKO, Paper 12b-5, Society of Instrumentation and Control, 1979.*
- *Miller, R. W., "Flow Measurement Engineering Handbook", McGraw-Hill Book Company, 1983.*
- *Daugherty, R. L., and Franzini, J. B., "Fluid Mechanics with Engineering Applications", McGraw-Hill Book Company, 1977.*